# Role of Core Stability and Dynamic Balance in Biathlon Standing Shooting

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**Key Words:** postural stability, rifle stability, athlete assessment, balance control

## 1.0 Abstract

While the importance of proficient standing shooting is well documented for overall biathlon race success, much less is known regarding physical qualities which may be prerequisites for standing shooting. This study examines the hypothesis that core stability may be one important parameter. Twenty-two biathletes varying in age and experience level completed a biathlon specific core stability assessment and a common clinical movement screen for dynamic stability, the Y-Balance Test (YBT). They then performed dryfire shooting sessions while postural and rifle stability were assessed using IMU units attached to the pelvis and rifle. Twelve variables quantifying range of motion (ROM) and velocity of rifle and body center of mass (COM) were calculated and associations between core stability and shooting variables assessed. Results revealed core stability was lower in both youth and master's level athletes than senior athletes. Across all groups, core stability was strongly associated with six of the twelve shooting measures including: rifle ROM across the line of fire ($r$ = .690, p < .001), rifle velocity in-line with line of fire direction ($r$ = .622, p =.002), rifle velocity in the vertical direction ($r$ = .643, p = .001), COM ROM across the line of fire ($r$ = .541, p = .009), COM ROM in-line with the line of fire ($r$ = .548, p = .008), and COM velocity across the line of fire ($r$ = .520, p = .013). All correlation coefficients were positive, indicating that worse core stability was associated with worse performance on these shooting measures. Performance on the YBT was a predictor of performance on the core stability assessment ($R^2$ = .304, p = .007), suggesting the YBT could be used as a surrogate measure of core stability if force plates are not available. These results have implications for development physical training programs for biathletes as well as providing insight for future studies into the important role of core musculature for both biathlon skiing and shooting performance.

## 2.0 Executive Summary

Several studies have documented the importance of standing shooting performance for overall race outcomes across a variety of biathlon race formats. As a result, investigators have quantified critical mechanical factors for standing shooting performance. Studies have also compared differences between high and low performing shooters, showing that high performing shooters display less body and rifle sway in the time window right before the shot is released. While these results provide insight into what athletes must do to shoot successfully in standing position, to date it remains unclear what are the physical capabilities required for them to do so.

This project proposes two potential physical qualities which may be related to shooting performance: core stability and dynamic balance control. Core stability is defined as the body's ability to control the torso and maintain equilibrium trunk and pelvis position following perturbations. Our laboratory quantifies core stability using a novel core stability assessment where athletes sit upright on an unstable surface while attempting to remain as still as possible. To make the assessment sport specific they assume upper body standing position and hold their rifle sight on a dryfire target. While this protocol can objectively quantify core stability in all three planes, it requires the use of laboratory equipment such as force plates, which may not be available in many coaching or training environments.

A potential solution would be to use simple movement screens designed to assess dynamic stability. Dynamic stability is defined as the ability to maintain equilibrium while moving the body center of mass (COM) outside the base of support. It can be easily quantified using the Y-Balance Test (YBT). While the YBT has been used to quantify dynamic balance and injury risk in numerous sports, it has not yet been applied in nordic skiing athletes or biathletes. If dynamic balance is predictive of core stability performance then the YBT may provide coaches an easy to implement tool for monitoring athlete development which they could employ in any training environment.

Therefore the purpose of this study was to examine associations between core stability and standing shooting performance under resting and elevated heart rate conditions across a range of biathletes varying in both age and skill level. A secondary purpose was to determine whether dynamic balance assessment predicted performance on the biathlon specific core stability assessment.

We recruited 22 biathletes varying in age and experience to participate. The cohort included 8 youth athletes, 6 senior level athletes, and 8 master's athletes. Half the individuals were tested in the Neuromuscular Biomechanics Laboratory at Montana State University and the other half were tested at the 2022 USBA National Championships in Lake Placid, NY. Participants completed the YBT, the biathlon specific core stability assessment, and then dryfired 4 5-shot magazines. Movement of the rifle and whole body COM were measured using IMU sensors placed on the sacrum and bottom of the rifle sight, respectively. Participants tested in the laboratory completed the protocol with both resting and elevated heart rates while participants tested in Lake Placid only completed the resting heart rate protocol.

YBT performance was quantified based on the reach distances in each of the three directions and core stability was quantified using the motion of the center-of-pressure on the force plate. IMU data were used to determine the range of motion (ROM) and mean velocity of the rifle and body COM in-line with the line of fire, across the line of fire, and in the vertical direction. All measures were calculated in the 0.5 seconds preceding the shot release.

Results showed the youth and master's athletes had less years of biathlon experience than the senior athletes. Both youth and master's athletes displayed worse core stability and dynamic balance control than senior level athletes. Collapsing across groups, core stability was significantly correlated with six of the shooting variables including rifle ROM across the line of fire, rifle velocity in-line with line of fire direction, rifle velocity in the vertical direction, COM ROM across the line of fire, COM ROM in-line with the line of fire, and COM velocity across the line of fire. All correlation coefficients were positive, indicating that worse core stability was associated with worse performance on these shooting measures.

Most shooting related variables increased from the resting heart rate to elevated heart rate conditions. In the elevated heart rate condition core stability was also strongly associated with six of the shooting variables including rifle ROM in-line with the line of fire, rifle ROM across the line of fire, rifle velocity across the line of fire, COM ROM across the line of fire, and COM velocity across the line of fire. All correlation coefficients were positive indicating that worse core stability was associated with worse shooting performance.

Lastly, linear regression models showed that performance on the YBT was able to predict core stability performance. The two tests were negatively associated with each other such that a smaller YBT composite score (i.e. worse performance on the YBT) predicted larger core stability scores (i.e worse performance on the core stability assessment).

Findings from this study have specific applications for biathlon performance and training. Core stability was strongly associated with numerous variables which are important critical factors for successful standing shooting. Coaches and athletes should consider incorporating specific exercises which develop core stability in their regular physical training. This may be especially true for younger athletes or master's athletes just starting into the sport given that they displayed worse core stability than senior level athletes. It may be that developing a sufficient threshold of core stability is a prerequisite for reaching a certain level of proficiency in standing shooting. This may be especially true when trying to shoot with fatigue. Finally, that YBT performance predicted core stability performance suggests the YBT may be a tool coaches could use as a surrogate measure for assessing core stability in environments which do not have access to laboratory resources.

## 3.0 Research Project Report

### 3.1 Research Topic and Objectives

All biathlon races involve both prone and standing shooting. Of the two, standing shooting is arguably the most important for determining race outcomes. Shooting in the standing position is always the last shooting round allowing minimal time to recover from any mistakes. Standing shooting is also performed with the most fatigue resulting in lower hit rates than prone shooting, across multiple race formats.[1,2] With lower hit rates, penalty time following standing shoots represents a greater portion of total race time than penalty times from prone shooting. Indeed, in pursuit races in particular, penalty lap time following standing shooting ranks second only to overall starting position in determining finishing places.[3] Therefore, maximizing performance during standing shooting is crucial for overall race success.

To this end, several studies have investigated critical factors in standing shooting and how these factors vary across age groups or performance levels. Multiple authors have shown that minimizing body and rifle sway across the line of shooting are important for maximizing standing shooting performance, and that these variables worsen when shooting following high intensity exercise.[4–7] It has also been shown that high performing and/or senior level, biathletes display less postural and rifle sway than lower performing and/or youth biathletes.[7,8] Given these biomechanical differences across performance levels, several authors have investigated ways to improve stability during standing shooting. Some of these studies have focused on using specialized training environments such as performing aiming holds in hypoxic conditions.[9] Others have focused on mindfulness,[10] imagery,[11] relaxation,[12] or other mind-body techniques.[13]

A current gap in this literature is the physical characteristics required for successful standing shooting. This gap is highlighted by the results of a recent review article examining physiologic, biomechanical, and psychological factors influencing shooting performance. None of the thirteen cited biathlon shooting studies reference physical qualities.[14] One potential reason for this gap is the lack of clarity regarding what physical qualities should be investigated. The underlying hypotheses of this research project propose two potential physical qualities which may be related to shooting performance: core stability and dynamic balance control.

Core stability is defined as the body's ability to control the torso to maintain equilibrium trunk and pelvis positions following internal or external perturbations.[15] While the importance of core stability has been recognized for many athletic activities,[15–20] it is usually in the context of providing a solid foundation for the production, transfer, and control of forces from the upper to lower extremities. While this is certainly important during the skiing component of biathlon races,[20] during standing shooting core stability may be important for a different reason. During shooting, a biathlete is subjected to internal perturbations from breathing or fatigue and external perturbations from environmental factors such as wind. If they have poor core stability, they may be unable to resist these perturbations, resulting in greater torso motion, greater postural sway, increased rifle sway, and overall worse shooting performance. These detrimental effects are likely amplified while shooting following exertion as multiple studies have shown that fatiguing the core musculature results in increased postural sway.[21–26] Despite this potentially important connection, the role of core stability in biathlon shooting has yet to be investigated.

One reason why this might be the case is that core stability can be difficult to quantify.[16] Many studies which discuss core stability,[16–19] including in the Nordic skiing literature,[20] instead measure core strength or core endurance. While these factors are important, in a shooting specific context, they would not help athletes minimize their postural or rifle sway. In contrast, recent studies on core stability and running mechanics have proposed a core stability assessment protocol which quickly and objectively quantifies stability in all planes.[15,27] This protocol was originally developed for use in runners where poor or reduced core stability increases the occurrence of injury related running mechanics[15,27] and we have adapted the protocol to be biathlon specific. However, it still requires the use of a force plate or pressure mat, equipment which many biathlon clubs, especially at the youth level may not have at their disposal. Even if core stability is strongly related to shooting performance, if coaches cannot measure it and track improvement over time, then the translational impact of this finding will be minimal.

A possible solution to this issue could be that coaches measure overall dynamic balance abilities instead of core stability specifically. Dynamic balance is the ability to maintain equilibrium while moving the body center of mass outside the base of support and can be easily quantified using common clinical tests such as the Y-Balance Test (YBT). The YBT requires participants to maintain balance on single limb while reaching as far as possible with the non-stance limb in anterior, posterior medial, and posterior lateral directions.[28] The YBT has been used to quantify dynamic balance in numerous sports,[29–33] and to examine injury risk in runners.[34,35] However, despite having the potential to provide insight into both skiing and shooting performance, to date the YBT has not been used for movement screening in Nordic skiing or biathlon athletes. If dynamic balance is related to core stability in biathletes, then the YBT would provide coaches, especially of youth clubs, an easily implemented tool for monitoring athlete development which they could employ in any training environment.

Given these gaps in knowledge the purposes of this project was two-fold. First, we examined associations between core stability and standing shooting performance under resting and elevated heart rate conditions across a range of biathletes varying in both age and skill level. Second, we examined associations between core stability performance and YBT performance. It was hypothesized that worse core stability would be associated with worse standing shooting performance (lower scores, increased postural and rifle sway) in all biathletes, that youth and master's athletes would display worse core stability and dynamic balance control than senior athletes, and that YBT performance would be highly correlated with performance on the biathlon specific core stability assessment.

## 3.2 Methodology

### 3.2.1 Participants

We recruited 22 individuals to participate in this study. Our participants ranged in age and biathlon experience as shown in Table 1. Half the participants were recruited from the biathlon program at the Crosscut Mountain Sports Center in Bozeman, Montana. These participants were assessed between December 2021 and March 2022 in the Neuromuscular Biomechanics Laboratory on the campus of Montana State University. These participants completed a protocol which included both resting and elevated heart rate shooting. The other half of the participants were from biathlon clubs around the United States and were assessed at the 2022 US Biathlon National Championships, held in Lake Placid, NY in March 2022. Since these participants were assessed the day before their major championship race they only completed the resting heart rate portion of the protocol.

Table 1. Participant demographics

| Category | Sex | Age (years) | Height (m) | Mass (kg) | Experience (years) |
|---|---|---|---|---|---|
| Youth (n=8) | 3M / 5F | 14.2 (± 1.3) | 1.69 (± 0.08) | 60.9 (± 5.7) | 3.1 (± 2.1) |
| Senior (n=6) | 2M / 4F | 23.0 (± 4.9) | 1.72 (± 0.12) | 65.7 (± 10.6) | 5.7 (± 1.9) |
| Masters (n=8) | 2M / 6F | 51.5 (± 11.5) | 1.71 (± 0.07) | 61.7 (± 7.3) | 3.5 (± 2.1) |

3.2.2 Protocol

Participants performed a 10-minute self-selected warm up which consisted of either jogging on a treadmill or cycling on a stationary bike. They then completed the YBT assessment (Figure 1). Participants were instructed to reach as far as possible in the anterior, posterior-lateral, and posterior medial directions while maintaining balance on the single stance limb. They were also instructed to keep their hands on their hips and not allow the stance limb heel to raise off the floor during the movement. In addition to verbal instructions, participants were provided a visual demonstration of the movement and allowed practice trials. If needed corrective feedback targeting the hands-on-hips or heel raise was provided during these trials. Two trials were then performed on the participant's dominant leg, with 1-minute of rest between trials.

Participants then completed the core stability assessment (Figure 1). This assessment is a modification of classical postural stability tests and is specifically designed to isolate the participant's ability to control the motion of their lumbar spine and torso independent from the lower extremity. The participant was instructed to sit as still as possible for 30-seconds on an unstable surface placed on top of a rigid stool sitting on a force platform. The force platform was located 5-meters from a wall to which a scaled dry fire target was attached. To add a sport specific secondary distraction task participants were asked to hold their rifle in the standing position (i.e. support arm on pelvis) and hold the rifle still on one of the bulls on the dryfire target.

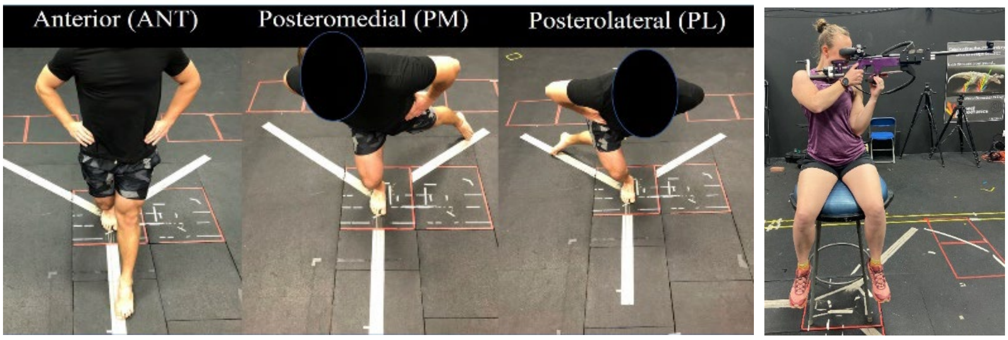


**Figure 1.** The three reach directions of the Y-balance test assessment (left) and the biathlon specific core stability assessment (right).

Following YBT and stability assessments, participants performed dry fire standing shooting of four 5-shot magazines with resting heart rate (all participants) followed by an elevated heart rate (participants tested in laboratory only). The protocol to elevate the heart rate involved the participant completing a 1000 m running interval on a treadmill. Participants were allowed to self-select the speed but were instructed to using a speed which approximated a speed they would use for a difficult threshold interval session. Movement of the rifle was quantified using an inertial measurement unit (IMU, Delsys Corp., Natick, MA USA) attached to the bottom of the front sight. A second IMU was attached to a rigid plastic cluster placed on the posterior pelvis to measure postural sway. Both IMU units contained tri-axial accelerometers, gyroscopes, and magnetometers, were synchronized, and data were sampled at 75 Hz..

3.2.3 Data Analysis

The maximum YBT reach distance in each direction was measured and a composite score was calculated as the sum of the three directions divided by three times the participant's leg length. Values from the two trials were averaged to determine the final value for each participant to use in statistical analysis.

Core stability was assessed by quantifying the movement of the center of pressure during the 30-second trials. COP data was filtered using a low-pass Butterworth filter with a 10 Hz cutoff.[15] The area of 95% confidence ellipse centered on the mean of the anterior-posterior and mediolateral COP coordinates was calculated. This measure has been used frequently in previous studies on postural control. The mean ellipse area from both trials was calculated, with higher values indicating worse core stability.

IMU data from the pelvis and rifle sensors were processed using a freely available sensor fusion algorithm to derive the sensor orientations.[36] These orientations were then rotated so the heading direction was aligned with the shooting direction, thus allowing the sensors to report motion in-line with the line of fire, across the line of fire, and in the vertical direction. Acceleration due to gravity was removed from the vertical acceleration signal. Linear accelerations were then double integrated to calculate velocities and displacements. To control for sensor drift, and derive shooting measures consistent with previous studies,[6,7] integrations were performed over small time windows of 0.5 seconds before each shot. The instant of each shot was determined using a spike in the linear accelerometer signal aligned with the long axis of the rifle barrel. Thus, all shooting measures were assessed in the final 0.5 seconds before the shot was fired. Ranges of motion were calculated as the total displacements during this time window while velocities were the mean velocities during this time window.

3.2.4 Statistical Analyses

Univariate analyses of variance (ANOVAs) were used to compare differences in age, biathlon experience, core stability, YBT performance, and shooting performance variables between youth, senior, and master's groups. Paired t-tests were used to evaluate changes in shooting measures from resting to elevated heart rate conditions for the cohort that performed both conditions. Pearson product moment correlations were used to evaluate associations between core stability and shooting performance variables in both resting and elevated heart rate conditions. Finally, simple linear regression was used to evaluate whether performance on the YBT predicted performance on the core stability assessment.

### 3.3 Results

Unsurprisingly, there was a difference in ages among the groups ($F_{2,19}$ = 55.53, $p < .001$), with the master's group being older than either the senior ($p < .001$) or youth ($p < .001$) groups and the senior group being older than the youth group ($p = .043$). However, it was somewhat surprising that there were minimal differences in years of biathlon experience across groups ($F_{2,19}$ = 3.55, p = 0.043). The senior group had more years of experience than either the youth (p = .022) or masters (p = .048) groups while the youth and master's groups were not statistically different (p = .697). In this regard, the groups can be considered as individuals relatively new to biathlon, at either younger or older ages, and experienced senior level competitors.

3.3.1 Associations Between Core Stability and Shooting Performance

Mean values for core stability and shooting performance variables during the resting heart rate condition for each group are shown in Table 2. Core stability was significantly different across groups ($F_{2,19}$ = 9.386, p = .001). Master's athletes had greater ellipse areas (worse core stability) than both youth (p = .045) and senior (p < .001) athletes. Youth athletes also displayed larger ellipse areas (worse core stability) than senior athletes (p = .025). Collapsing across groups, core stability was significantly correlated with six of the shooting variables including rifle ROM across the line of fire (*r* = .690, p < .001), rifle velocity in-line with line of fire direction (*r* = .622, p =.002), rifle velocity in the vertical direction (*r* = .643, p = .001), COM ROM across the line of fire (*r* = .541, p = .009), COM ROM in-line with the line of fire (*r* =

**Table 2.** Mean (± standard deviation) for the core stability, YBT, and shooting related variables from the resting shooting bout. Superscript a and b indicate significantly different than youth or senior, respectively.

| Variable | Youth (n=8) | Senior (n = 6) | Masters (n = 8) |
|---|---|---|---|
| Core stability ($mm^2$) | 187.22 (± 13.58)$^{b}$ | 130.32 (± 28.43) | 231.53 (± 65.7)$^{a,b}$ |
| YBT composite score | 0.904 (± 0.046)$^{b}$ | 0.984 (± 0.022) | 0.799 (± 0.122)$^{a,b}$ |
| Rifle ROM inline (mm) | 1.77 (± 0.24) | 1.80 (± 0.28) | 2.08 (± 0.31) |
| Rifle ROM across (mm) | 3.15 (± 0.86)$^{b}$ | 2.50 (± 0.39)$^{a}$ | 4.19 (± 1.27)$^{a,b}$ |
| Rifle ROM vertical (mm) | 1.91 (± 0.17) | 2.33 (± 0.75) | 2.87 (± 0.89)$^{a}$ |
| Rifle velocity inline (mm/s) | 3.77 (± 0.47) | 3.83 (± 0.58) | 5.01 (± 0.81)$^{a,b}$ |
| Rifle velocity vertical (mm/s) | 6.97 (± 0.91) | 5.87 (± 1.07) | 8.12 (± 2.47)$^{a,b}$ |
| Rifle velocity across (mm/s) | 4.71 (± 0.49) | 3.71 (± 1.65) | 5.72 (± 1.76)$^{a,b}$ |
| COM ROM across (mm) | 2.16 (± 0.71) | 1.85 (± 0.73) | 3.06 (± 0.66)$^{a,b}$ |
| COM ROM inline (mm) | 0.63 (± 0.28) | 0.48 (± 0.11) | 0.93 (± 0.37)$^{a,b}$ |
| COM ROM vertical (mm) | 0.54 (± 0.35) | 0.35 (± 0.16) | 0.36 (± 0.11) |
| COM velocity across (mm/s) | 3.65 (± 1.13) | 3.71 (± 1.16) | 5.17 (± 1.09)$^{a,b}$ |
| COM velocity inline (mm/s) | 3.26 (± 1.86) | 2.44 (± 0.28) | 3.73 (± 1.66) |
| COM velocity vertical (mm/s) | 2.84 (± 2.42) | 1.39 (± 0.68) | 1.44 (± 0.54) |

.548, p = .008), and COM velocity across the line of fire (*r* = .520, p = .013). All correlation coefficients were positive, indicating that worse core stability was associated with worse performance on these shooting measures.

Only twelve senior (n=6) and master's (n=6) athletes completed the elevated heart rate protocol. Of the twelve shooting variables analyzed, five of the rifle stability related variables increased from the resting heart rate condition. These included ROM of the rifle inline with the line of fire (p < .001, %change = 35.2%), ROM of the rifle across the line of fire (p < .001, %change = 38.3%), ROM of the rifle in the vertical direction (p = .04, %change = 18.6%), rifle velocity inline with the line of fire (p = .04, %change = 22.9%), and rifle velocity across the line of fire (p = .017, %change = 17.9%). None of the COM stability related variables increased from resting to elevated heart rate.

In the elevated heart rate condition core stability was also strongly associated with six of the shooting variables including rifle ROM inline with the line of fire (*r* = .637, p = .026), rifle ROM across the line of fire (*r* = .833, p < .001), rifle velocity across the line of fire (*r* = .788, p =.002), COM ROM across the line of fire (*r* = .640, p .025), and COM velocity across the line of fire (*r* = .651, p = .022). All correlation coefficients were positive indicating that worse core stability was associated with worse shooting performance.

Scatter plots showing the relationship between core stability and selected shooting metrics in both resting and elevated heart rate conditions are shown below in Figure 2.

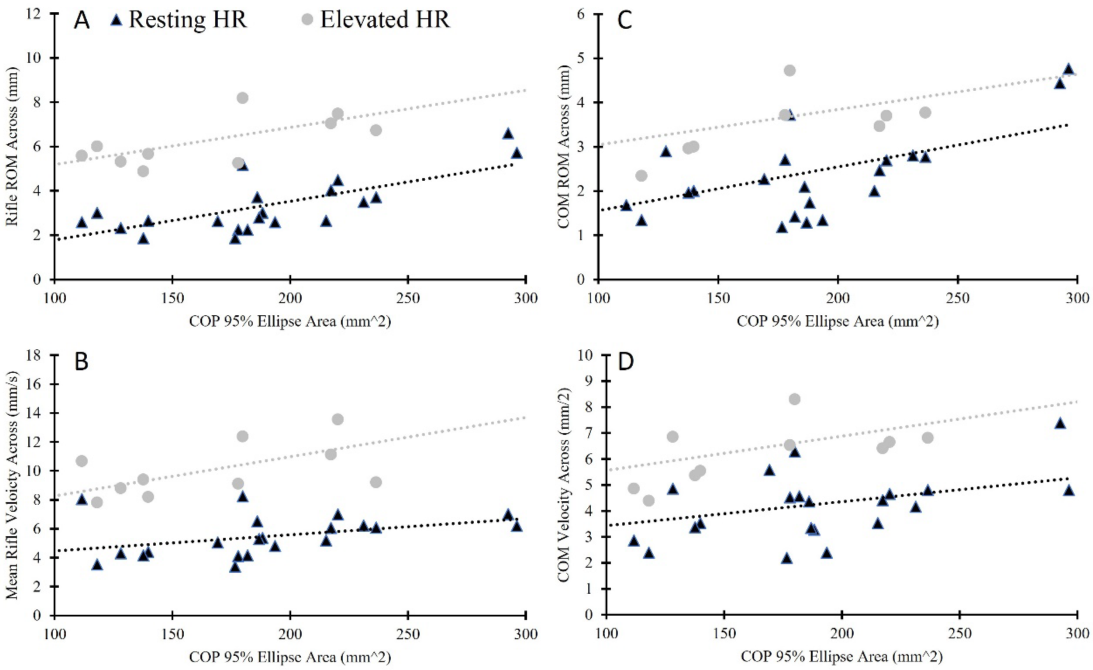


**Figure 2.** Scatter plots showing the relationship between rifle range of motion across the line of fire (A), mean rifle velocity across the line of fire (B), COM range of motion across the line of rife (C), and mean COM velocity across the line of fire (D).

### 3.3.2 Core Stability and Dynamic Balance

A linear regression model showed that performance on the YBT was able to account for 30.4% of the variance in core stability scores ($R^2$ = .304, p = .007, Figure 3). The two tests were negatively associated with each other (*r* = -.551, p = .007) such that a smaller YBT composite score (i.e. worse performance on the YBT assessment) predicted larger core stability scores (i.e. worse performance on the core stability assessment).

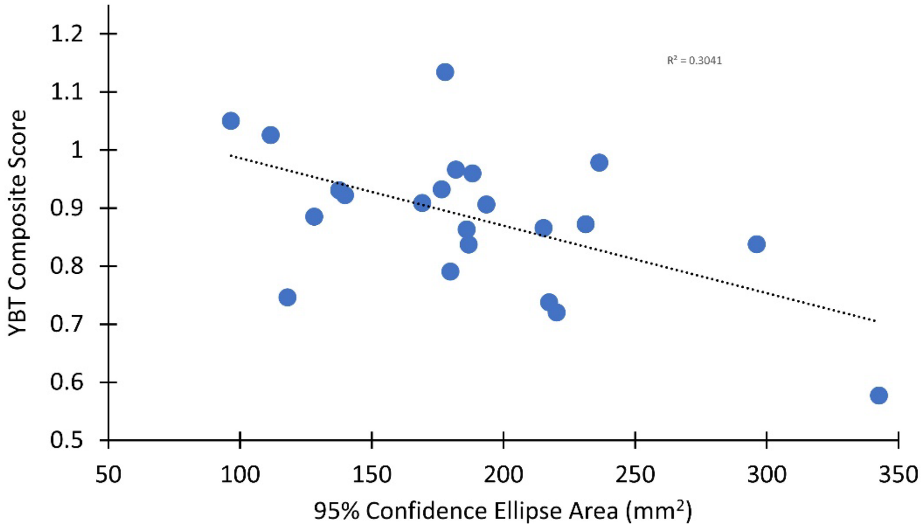


**Figure 3.** Relationship between performance on the biathlon specific core stability assessment and the YBT assessment.

**3.4 Conclusions and Recommendations**

There are several main findings from this study each with unique applications or implications for biathlon performance and training. These include the fact that core stability is highly related to shooting performance and differs across age groups, and that YBT performance predicts performance on the biathlon specific core stability protocol. An ancillary outcome from this study is the methodologies used to assess shooting performance. Each of these is discussed below in further detail.

3.4.1 Core stability is associated with shooting performance and differs across age groups

Core stability was strongly associated with numerous variables which are important critical factors for successful standing shooting. In this regard, coaches and athletes should consider incorporating specific exercises which develop core stability in their regular physical training. This may be especially true for younger athletes or master's athletes just starting into the sport given that they displayed worse core stability than senior level athletes. It may be that developing a sufficient threshold of core stability is a prerequisite for reaching a certain level of proficiency in standing shooting.

Exactly how to best approach this remains a question for further investigation. Many traditional core training exercises focus on either strengthening core muscles by moving against resistance (i.e. crunches, sit-ups, back extensions and their derivations) or on maintaining postures in isometric holds (i.e. planking exercises and their derivations). Exercises which specifically target maintaining a posture while resisting perturbations designed to disrupt that posture might be most effective for core strengthening in a manner which has direct translation to enhancing biathlon performance.

3.4.2 Core stability and fatigue

In general, associations between core stability and shooting mechanics were larger in the elevated heart rate condition than the resting heart rate condition. This finding may reflect the increased importance of core stability when trying to shoot with fatigue such as in the last shooting of a four-shooting race. It has been shown that fatiguing the core musculature substantially impairs skiing performance.[20] In biathlon this fatigue might also be impairing shooting performance. To further elucidate this effect future studies could pursue to possible pathways. First, the natural decrease in core stability throughout the course of a race could be quantified. Second, investigators could apply core stability knock down protocols such as those which have been used to investigate the impact of reducing core stability on running mechanics.[15] Pairing the deficits induced by a knock down protocol with the magnitudes of decreased stability observed in actual races could provide innovative benchmarks for preseason physical readiness testing while also giving coaches insight into how athletes may perform late in a race.

3.4.2 YBT predicts performance on core stability and could be used as a surrogate measure

The core stability measure used in the current study was derived from classic assessments of postural sway. However, this method likely is not applicable to all athletes as it requires specialized equipment (i.e. a force plate) to measure. In contrast, the YBT requires minimal to no equipment and thus could be performed by coaches in a wide variety of environments. Performance on the YBT was able to predict performance on the core stability test suggesting that this approach might be especially effective for coaches with limited resources or which supervise large cohorts of athletes.

Using the YBT in this manner might provide additional insight for coaches, especially regarding deficits in skiing technique. Good performance on the YBT requires the ability to stabilize the body with the stance limb joints in flexion while freely moving the non-stance limb. Similar capabilities are required for achieving full weight transfer and glide during skate skiing. Interestingly, while the YBT has been used to quantify dynamic balance in numerous sports,[29–33] it has not yet been used extensively in the Nordic skiing literature. This is an opportunity for incorporation of simple movement screens which may give coaches and athletes insight into physical capabilities required for efficient ski technique.

3.4.3 Single IMU sensors can quantify postural and rifle stability during shooting.

The last outcome from this study concerns the methodology used to assess postural and rifle stability during shooting. Previous studies measuring these parameters have all used 3D motion capture and force plates to quantify rifle and body stability.[4–7] This equipment is expensive, not widely available, and often requires use of research laboratories. Combined these reasons may be why mechanical diagnostics of shooting performance remain relatively rare and limited to high level athletes. Leveraging the rapidly expanding field of wearable sensor technology, as done in the current study, may alleviate this issue.

Review articles have shown that a single IMU placed on the sacrum is a frequent and valid method for assessing postural stability across a variety of populations.[37,38] Specific to Nordic skiing, a single IMU sensor, either on the sacrum[39] or on the chest[40] can quantify skiing technique with sufficient detail to have some training and coaching benefit. Building on this literature, it is possible to envision a system with two IMU sensors, one on the rifle and one on the sacrum which would allow simultaneous and continuous monitoring of both ski technique and shooting mechanics while providing real-time feedback which coaches could use to identify needed corrections. The approach used in this study is a step in this direction and, with refinement could lead to development of such a system.

3.4.4 Overall summary

In summary, this study evaluated the relationship between core stability, dynamic balance control, and standing shooting performance. Our main results were that core stability is strongly associated with numerous shooting measures, that core stability differs across different levels of biathletes, and that simple clinical movement screens such as the YBT could be used to predict core stability. Each of these findings has applications to biathlon training and coaching, and each provides insights and rationale for future research into this topic.

**3.5 References**

1. Luchsinger H, Kocbach J, Etttema G, Sandbakk Ø. The contribution from cross-country skiing and shooting variables on performance level and sex differences in biathlon World Cup individual races. 148:148-162.
2. Luchsinger H, Karsten B, Baker J, et al. Comparison of Performance Level and Sex on Sprint Race Performace in the Biathlon World Cup. *Int J Sports Physiol Perform*. 2017;14(2):156-162. https://www.cochranelibrary.com/central/doi/10.1002/central/CN-01787161/full
3. Luchsinger H, Kocbach J, Ettema G, Sandbakk Ø. Contribution from cross-country skiing, start time and shooting components to the overall and isolated biathlon pursuit race performance. *PLoS One*. 2020;15(9 September). doi:10.1371/journal.pone.0239057
4. Ihalainen S, Laaksonen MS, Kuitunen S, et al. Technical determinants of biathlon standing shooting performance before and after race simulation. *Scand J Med Sci Sport*. 2018;28(6):1700-1707. doi:10.1111/sms.13072
5. Sadowska D, Krzepota J, Klusiewicz A. Postural balance and rifle stability in a standing shooting position after specific physical effort in biathletes. *J Sports Sci*. 2019;37(16):1892-1898. doi:10.1080/02640414.2019.1603136
6. Sattlecker G, Buchecker M, Müller E, Lindinger SJ. Postural balance and rifle stability during standing shooting on an indoor gun range without physical stress in different groups of biathletes. *Int J Sport Sci Coach*. 2014;9(1):171-183. doi:10.1260/1747-9541.9.1.171
7. Sattlecker G, Buchecker M, Gressenbauer C, Müller E, Lindinger SJ. Factors discriminating high from low score performance in biathlon shooting. *Int J Sports Physiol Perform*. 2017;12(3):377-384. doi:10.1123/ijspp.2016-0195
8. Baca A, Kornfeind P. Stability analysis of motion patterns in biathlon shooting. *Hum Mov Sci*. 2012;31(2):295-302. doi:10.1016/j.humov.2010.05.008
9. Czuba M, Bril G, Płoszczyca K, et al. Intermittent hypoxic training at lactate threshold intensity improves aiming performance in well-trained biathletes with little change of cardiovascular variables. *Biomed Res Int*. 2019;2019. doi:10.1155/2019/1287506
10. Josefsson T, Gustafsson H, Iversen Rostad T, Gardner FL, Ivarsson A.

Mindfulness and shooting performance in biathlon. A prospective study. *Eur J Sport Sci*. 2021;21(8):1176-1182. doi:10.1080/17461391.2020.1821787
11. Groslambert A, Candau R, Grappe F, Dugué B, Rouillon JD. Effects of autogenic and imagery training on the shooting performance in biathlon. *Res Q Exerc Sport*. 2003;74(3):337-341. doi:10.1080/02701367.2003.10609100
12. Laaksonen MS, Ainegren M, Lisspers J. Evidence of Improved Shooting Precision in Biathlon After 10 Weeks of Combined Relaxation and Specific Shooting Training. *Cogn Behav Ther*. 2011;40(4):237-250. doi:10.1080/16506073.2011.616217
13. Grebot C, Groslambert A, Pernin JN, Burtheret A, Rouillon JD. Effects of exercise on perceptual estimation and short-term recall of shooting performance in a biathlon. *Percept Mot Skills*. 2003;97(3 II):1107-1114. doi:10.2466/pms.2003.97.3f.1107
14. Laaksonen MS, Finkenzeller T, Holmberg HC, Sattlecker G. The influence of physiobiomechanical parameters, technical aspects of shooting, and psychophysiological factors on biathlon performance: A review. *J Sport Heal Sci*. 2018;7(4):394-404. doi:10.1016/j.jshs.2018.09.003
15. Chaudhari AMW, VAN Horn MR, Monfort SM, Pan X, Oñate JA, Best TM. Reducing Core Stability Influences Lower Extremity Biomechanics in Novice Runners. *Med Sci Sports Exerc*. 2020;52(6):1347-1353. doi:10.1249/MSS.0000000000002254
16. Kibler W Ben, Press J, Sciascia A. The role of core stability in athletic function. *Sports Med*. 2006;36(3):189-198. doi:10.2165/00007256-200636030-00001
17. Leetun DT, Ireland ML, Willson JD, Ballantyne BT, Davis IMC. Core stability measures as risk factors for lower extremity injury in athletes. *Med Sci Sports Exerc*. 2004;36(6):926-934. doi:10.1249/01.MSS.0000128145.75199.C3
18. Reed CA, Ford KR, Myer GD, Hewett TE. The effects of isolated and integrated “core stability” training on athletic performance measures: A systematic review. *Sport Med*. 2012;42(8):697-706. doi:10.2165/11633450-000000000-00000
19. Dello Iacono A, Padulo J, Ayalon M. Core stability training on lower limb balance strength. *J Sports Sci*. 2016;34(7):671-678. doi:10.1080/02640414.2015.1068437
20. Bucher E, Sandbakk Ø, Donath L, Roth R, Zahner L, Faude O. Exercise-induced trunk fatigue decreases double poling performance in well-trained cross-country skiers. *Eur J Appl Physiol*. 2018;118(10):2077-2087. doi:10.1007/s00421-018-3938-4
21. Parreira RB, Amorim CF, Gil AW, Teixeira DC, Bilodeau M, Da Silva RA. Effect of trunk extensor fatigue on the postural balance of elderly and young adults during unipodal task. *Eur J Appl Physiol*. 2013;113(8):1989-1996. doi:10.1007/s00421-013-2627-6
22. Larson DJ, Brown SHM. The effects of trunk extensor and abdominal muscle fatigue on postural control and trunk proprioception in young, healthy individuals. *Hum Mov Sci*. 2018;57(April 2017):13-20. doi:10.1016/j.humov.2017.10.019
23. Davidson BS, Madigan ML, Nussbaum MA, Wojcik LA. Effects of localized muscle fatigue on recovery from a postural perturbation without stepping. *Gait Posture*. 2009;29(4):552-557. doi:10.1016/j.gaitpost.2008.12.011
24. Madigan ML, Davidson BS, Nussbaum MA. Postural sway and joint kinematics during quiet standing are affected by lumbar extensor fatigue. *Hum Mov Sci*.

2006;25(6):788-799. doi:10.1016/j.humov.2006.04.004
25. Vuillerme N, Anziani B, Rougier P. Trunk extensor muscles fatigue affects undisturbed postural control in young healthy adults. *Clin Biomech*. 2007;22(5):489-494. doi:10.1016/j.clinbiomech.2007.01.007
26. Ghamkhar L, Kahlaee AH. The effect of trunk muscle fatigue on postural control of upright stance: A systematic review. *Gait Posture*. 2019;72(October 2018):167-174. doi:10.1016/j.gaitpost.2019.06.010
27. Hoffee A, Monfort S, Becker J. Relationship Between Core Stability and Running Mechanics in Adolescent Runners. *Med Sci Sport Exerc*. 2020;52(7S):251.
28. Chimera NJ, Warren M. Use of clinical movement screening tests to predict injury in sport. *World J Orthop*. 2016;7(4):202-217. doi:10.5312/wjo.v7.i4.202
29. Butler RJ, Southers C, Gorman PP, Kiesel KB, Plisky PJ. Differences in soccer players' dynamic balance across levels of competition. *J Athl Train*. 2012;47(6):616-620. doi:10.4085/1062-6050-47.5.14
30. Butler RJ, Bullock G, Arnold T, Plisky P, Queen R. Competition-level differences on the lower quarter Y-balance test in baseball players. *J Athl Train*. 2016;51(12):997-1002. doi:10.4085/1062-6050-51.12.09
31. Smith CA, Chimera NJ, Warren M. Association of Y balance test reach asymmetry and injury in Division I Athletes. *Med Sci Sports Exerc*. 2015;47(1):136-141. doi:10.1249/MSS.0000000000000380
32. Gonell AC, Romero JAP, Soler LM. Relationship Between the Y Balance Test Scores and Soft Tissue Injury Incidence in a Soccer Team. *Int J Sports Phys Ther*. 2015;10(7):955-966.
33. Butler RJ, Lehr ME, Fink ML, Kiesel KB, Plisky PJ. Dynamic Balance Performance and Noncontact Lower Extremity Injury in College Football Players: An Initial Study. *Sports Health*. 2013;5(5):417-422. doi:10.1177/1941738113498703
34. Nelson S, Wilson C, Becker J. Kinetic Predictors of Y-Balance Test Performance. In: *Proceedings of the 67th Annual Meeting of the American College of Sports Medicine*. ; 2020.
35. Wilson C, Becker J. Does Y-Balance Test Performance Predict Injury Related Running Mechanics? *Med Sci Sport Exerc*. 2019;51(5):S351.
36. Madgwisk S, Harrison A, Vaidyanathan R. Estimation of IMU and MARG Orientation Using a Gradient Descent Algorthm. *IEEE Int Conf Rehabil Robot*. Published online 2011:1-7. https://doi.org/10.1109/%0AICORR.2011.5975346
37. Baker N, Gough C, Gordon SJ. Inertial sensor reliability and validity for static and dynamic balance in healthy adults: A systematic review. *Sensors*. 2021;21(15). doi:10.3390/s21155167
38. Ghislieri M, Gastaldi L, Pastorelli S, Tadano S, Agostini V. Wearable inertial sensors to assess standing balance: a systematic review. *Sensors (Switzerland)*. 2019;19(19):1-25. doi:10.3390/s19194075
39. Myklebust H, Gloersen O, Hallen J. Quantification of movement patterns in cross-country skiing using inertial measurement units. *J Appl Biomech*. 2015;31:492-498. https://brage.bibsys.no/xmlui/handle/11250/2422117
40. Stöggl T, Holst A, Jonasson A, et al. Automatic classification of the Sub-Techniques (Gears) used in cross-country ski skating employing a mobile phone. *Sensors (Switzerland)*. 2014;14(11):20589-20601. doi:10.3390/s141120589